Measurements of high p_T identified particles v_2 and v_4 in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions by PHENIX

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Abstract. The v_2 and v_4 of pions, kaons and protons have been measured by PHENIX in 200 GeV Au+Au collisions up to p_T~6 GeV/c and 4 GeV/c, respectively. The v_4 of all these identified particles have been found to scale with the number of constituent quarks and all these particles have a similar v_4/v_2^2 ratio which is close to 0.9. The scaling behavior of v_2 is studied at high-p_T and a deviations from the universal scaling is observed for transverse kinetic energy (K_{ET}/nq) higher than 1 GeV.

1. Introduction

A hot, dense non-hadronic matter has been created at RHIC in ultra-relativistic heavy ion collision[1]. The anisotropic flow coefficients v_2 and v_4 provide sensitive information about the properties of the matter in the earliest stages of the heavy-ion collisions. The v_2 of identified hadrons has been found to obey empirical scaling with the number of constituent quarks (NCQ) for K_{ET} and provides evidence that partonic degrees of freedom determine the early dynamics of the system[2]. In this work, the measurement of v_4 will be used to further test this scaling. The v_4/v_2^2 ratio has been proposed as a probe of ideal hydrodynamics and related to the degree of thermalization[3] in the system. Accurate measurements of identified particles v_4/v_2^2 ratio will constrain the model calculations. The measurement of high p_T identified hadron v_2 will allow us to test the limits of the NCQ scaling. If the anisotropic emission of particles in the high p_T region is dominated by parton energy loss, the NCQ scaling is expected to break since the energy loss mechanism affects all particle species similarly[4]. Determining the breaking point in the NCQ scaling will provide information on the limits of applicability of the hydrodynamic description of the system dynamics.

2. Analysis Method

During Run 7 of RHIC, the PHENIX experiment recorded 5.5 B minimum-bias 200 GeV Au + Au collision events and 2.2 B have been used for this work. Two new subsystem detectors were installed prior to Run 7, which significantly enhanced the

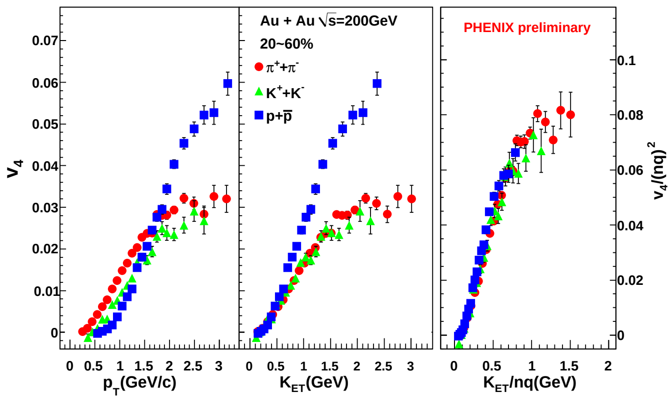

Figure 1. The v_4 of pions, kaons and protons for $20-60\%$ Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

PHENIX capabilities for identified particle anisotropic flow measurements . A time of flight detector(TOFw) was installed in the west arm of the PHENIX spectrometer. With $\sigma_t = 75$ ps intrinsic timing resolution, the TOFw detector allows pion/kaon separation up to p_T~2.8 GeV/c, and kaon/proton separation up to p_T~4.5 GeV/c. Together with the previously installed Aerogel Cherenkov counter (ACC), the TOFw detector provides high-p_T hadron identification in PHENIX. Combining the photon yield measured in the ACC and the mass-squared from TOFw, the kaon identification is extended to $p_T\sim$ 4 GeV/c, while the pion and proton identification reaches $p_T \sim$ 7GeV/c. PHENIX was also upgraded with a new reaction plane detector (RxNP) which covers the rapidity region $1.0 < |\eta| < 2.8$ with best resolution around 74% for v_2 measurements. Since the RxNP is installed away from mid-rapidity, the non-flow effects from jet correlation are relatively small.

3. Results

Figure 1 shows the v_4 of pions, kaons and protons in the $20-60\%$ centrality bin in 200 GeV Au+Au collisions. In the left plot, the v_4 is shown as a function of p_T. A clear mass ordering is observed for pions, kaons and protons, which is consistent with hydrodynamics behavior which has been previously observed for the elliptic flow. In the middle plot, the v_4 measurements are presented as a function of transverse kinetic energy K_{ET} =m_T-m_0. In this unit, the mass ordering disappears at low K_{ET} which is consistent with hydrodynamic predictions. For K_{ET} greater than about 0.5 GeV, kaons and pions show much less v_4 than protons. A universal behavior for baryons and mesons is observed when K_{ET} is divided by the nq (number of constituent quarks) and the v_4 values are divided by the nq^2. This universal behavior has also been observed in the measurements of v_2 for identified hadrons[2]. The results presented here further strengthen the conclusion that partonic flow has been built up in the early stages of the heavy-ion collisions at RHIC.

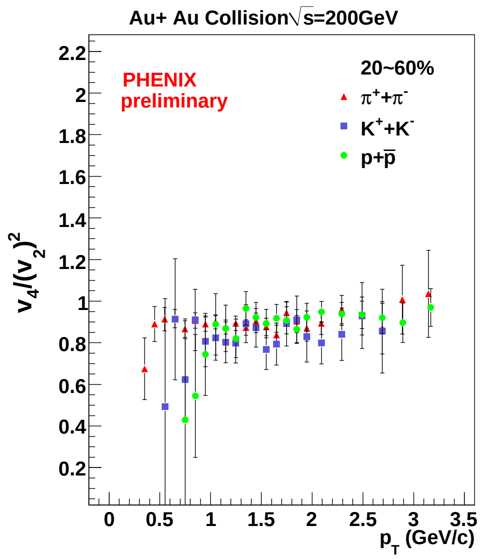

Figure 2. The v_4/v_2^2 for pions, kaons and protons as a function of p_T in the $20-60\%$ centrality class in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions.

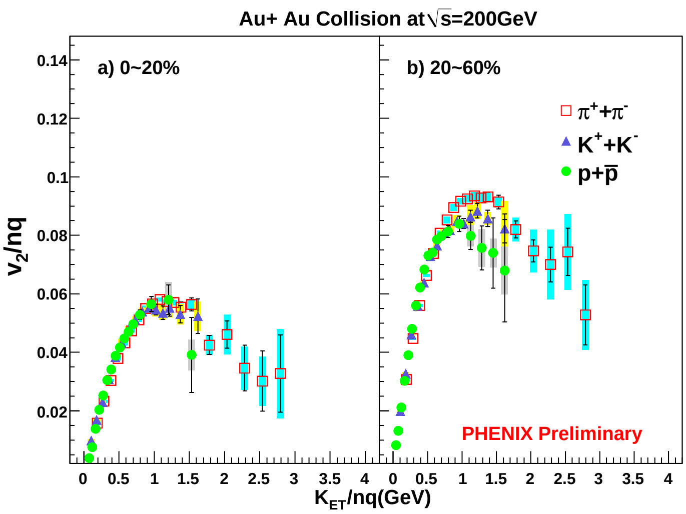

Figure 3. Constituent quark scaling of elliptic flow, v_2 for pions, kaons and protons as a function of transverse kinetic energy per quark (KE$_T$) measured in two centrality classes:(left)$0-20\%$, and (right) $20-60\%$.

Figure 2 shows the v_4/v_2^2 ratio for pions, kaons and protons as a function of p_T in the $20-60\%$ centrality bin. This ratio is flat with p_T in the measured range and is independent of the particle species within errors. We analyze the results in terms of a simple coalescence model:

$$\frac{v_{4,m}(2p_T)}{v_{2,m}^2(2p_T)} = \alpha\left(\frac{1}{4} + \frac{1}{2}\frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}\right) \qquad (1a)$$

$$\frac{v_{4,b}(3p_T)}{v_{2,b}^2(3p_T)} = \alpha(\frac{1}{3} + \frac{1}{3}\frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}) \tag{1b}$$

where $v_{4,m}(p_T)$, $v_{4,b}(p_T)$ and $v_{4,q}(p_T)$ represent the meson, baryon and quark v_4 respectively, and $v_{2,m}(p_T)$, $v_{2,b}(p_T)$ and $v_{2,q}(p_T)$ represent the meson, baryon and quark v_2. Using the measured v_4/v_2^2 ratio around 0.9 for both baryons and mesons, from equations (1a) and (1b), we obtain that the parton $v_{4,q}/v_{2,q}^2$ ratio is around 0.5 and the parameter α is around 1.8. This result indicates that a thermalized partonic liquid has been produced at RHIC.

Using the high-p_T elliptic flow results, we can study the limits of applicability of the hydrodynamic description. Figure 3 shows the v_2 of pions, kaons and protons as a function of K_{ET} in two centrality bins. Both v_2 and K_{ET} has been divided by the nq. The left plot is the result in the $0-20\%$ centrality bin, and the right plot is the result in the $20-60\%$ centrality bin. In $20-60\%$ collisions, the NCQ scaling begins to break as the K_{ET}/nq exceeds ∼1 GeV. This indicates that the origin of the v_2 is based in hydrodynamics collective flow and parton recombination in the low K_{ET} region, but above $K_{ET}/nq \sim 1$ GeV, the contribution from parton energy loss become increasingly important.

4. Conclusions

The measurements of pion, kaon and proton v_2 and v_4 have been extended up to a p_T of 6 GeV/c and 4 GeV/c respectively by PHENIX. The NCQ scaling has been tested for v_4 and been found to hold for K_{ET}/nq up to 1 GeV, indicating that partonic flow governs the bulk dynamics in heavy-ion collisions at RHIC. The mesons and baryons have a similar ratio of v_4/v_2^2, which is consistent with expectations for a thermalized partonic system in which hadrons at the intermediate p_T region are produced by parton recombination. The v_2 measurement shows that the NCQ scaling begins to break for K_{ET}/nq above 1 GeV in the $20-60\%$ centrality class, which suggests that hard-scattering may be the dominant production mechanism for both baryons and mesons in this K_{ET}/nq range and thus parton energy loss effects play a significant role in generating the azimuthal anisotropy in particle emission.

5. References

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